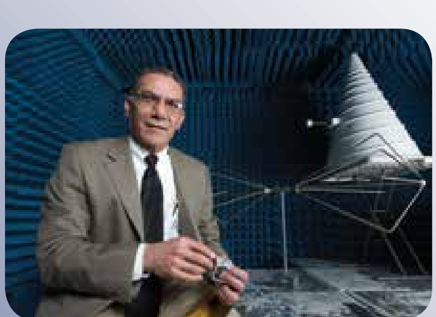
INL/MIS-12-27417

LABORATORY PLAN

PROVING THE PRINCIPLE OF NATIONAL ENERGY AND SECURITY SOLUTIONS USING WORLD-CLASS CAPABILITIES



Idaho National Laboratory

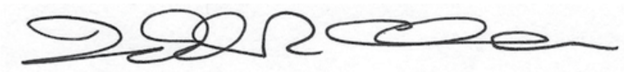
Todd Allen
Deputy Laboratory Director
Science & Technology

Idaho National Laboratory (INL) is the Department of Energy Office of Nuclear Energy (DOE-NE) lead laboratory. INL is the host to the nation's critical nuclear energy research capability. We supplement this core mission with expertise in national and homeland security and other clean energy technologies. In mission areas where INL is a national leader, we carry the nation's key capability: the people, the facilities, the knowledge, and the leadership.

Since INL was created in 2005, the Idaho site has changed in significant and transformational ways. The Research and Education Campus has become a true campus and center of the Laboratory. The Advanced Test Reactor Complex has a new look with aged buildings gone and modern facilities added. The Materials and Fuels Complex has added critical capabilities in fuel fabrication and post-irradiation examination. This year our Wireless Test Bed and our BioFeedstock Systems Laboratory were both designated as National User Facilities. This ongoing transformation, plus the fantastic world-leading staff, explains my enthusiasm for the Laboratory.

Hosting national infrastructure alone is not adequate in the 21st Century. Enabling the use of the capability by researchers including industry, academia, and national laboratories beyond INL is a necessary and proper use of the facilities entrusted to INL. To optimize the use of precious national resources, INL embraces the user facility model where we not only host the capability, but also make it available to researchers across the nation. Pairing the best ideas with the best capability must be our goal.

This plan presents the strategic vision for the Laboratory and is our introduction to a special place dedicated to improving our nation's energy security future.



"THE MORE YOU LOSE YOURSELF IN SOMETHING BIGGER THAN YOURSELF, THE MORE ENERGY YOU WILL HAVE."

NORMAN VINCENT PEALE

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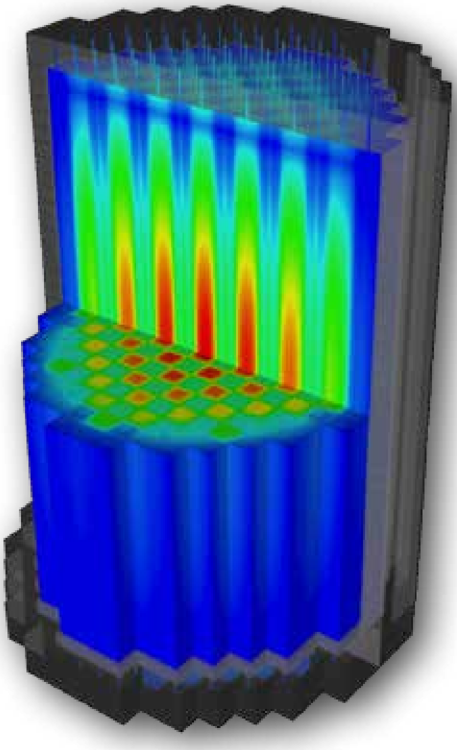
INL's secure and expansive physical space, as seen in this view of the Materials and Fuels Complex has a long history of safely conducting nuclear energy research.



INL is DOE's National Nuclear Energy Laboratory. A multi-program laboratory, INL also provides scientific and engineering solutions to meet the needs of the nation in other aspects of energy supply and national and homeland security. Battelle Energy Alliance, LLC (BEA) is the Management and Operations (M&O) contractor for INL.

INL is tasked by the Department of Energy to deliver on the following contract requirements:

- Advance the research and development (R&D) and engineering capabilities of INL in support of the DOE's principal nuclear energy and national security missions
- Establish an appropriate balance among nuclear fuel cycle and nuclear energy technology development, national security, and supporting missions
- Maintain a strong multi-program national laboratory recognized as a valuable science and engineering asset
- Advance missions through three primary directorates and two mission support centers
- Achieve and sustain excellence in operations, business innovation, and project management.

DOE's vision is for the INL to lead the Nation in the research, development, demonstration and deployment (RDD&D) of nuclear technologies to:

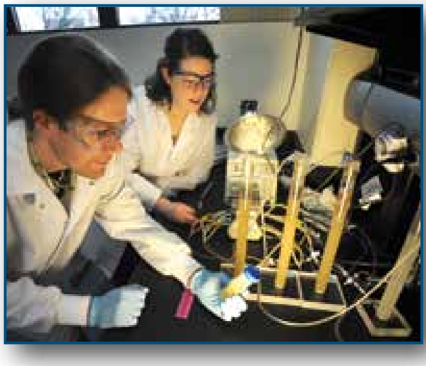
- Ensure that nuclear energy remains a competitive National choice in a diverse portfolio of energy technology options for our future
- Sustain the positive impact nuclear energy has on our efforts to reduce carbon emissions and mitigate the impacts of climate change
- Enable the success of National strategies for used nuclear fuel and waste disposition, and nuclear materials management
- Support U.S. global interests in nuclear technology safety and non-proliferation
- Enable U.S. exports and creation of American jobs by partnering with the private sector to sustain U.S. leadership in nuclear energy technology
- Fulfill a stewardship role in revitalizing the national nuclear enterprise intellectual and physical capabilities for the U.S.

INL will utilize its capabilities and infrastructures synergistically to support key U.S. National and Homeland Security (NHS), Energy, and Environmental technology needs.

INL is a science-based, applied engineering national laboratory dedicated to supporting DOE's missions in nuclear and energy research, science, and national defense. INL's mission is to ensure the nation's energy security by influencing the development of safe, competitive, and sustainable energy systems and unique national and homeland security capabilities. INL's approach is to combine impactful innovation with safe operations and sound engineering to address critical energy areas through RDD&D.

In the next 10 years INL will:

- Play a key role in enabling a successful Small Modular Reactor (SMR) demonstration
- Lead U.S. research to establish a robust technical basis for extended used fuel storage and disposal
- Perform first-in-the-world advanced post-irradiation examinations of irradiated fuels and materials
- Conduct streamlined steady-state irradiations in the ATR and transient irradiations in TREAT to enable advancements such as accident tolerant fuels
- Contribute to our National used fuel disposition efforts by examining (wet and dry), characterizing and repackaging DOE and commercial reactor fuels bound for interim storage or a repository. In performance of this transshipment role the Lab will investigate any unusual or unexpected inspection results and provide the certified data and records that accompany the fuel through disposal
- Lead an advanced reactor research program focused on power generation, process heat, waste minimization and material management, isotope production, GEN-IV International goals and interests, particularly fast reactors and gas reactors coupled with Brayton cycles
- Further advance the competitiveness of U.S. exports with pre-competitive research that reduces the cost and time to develop and license new nuclear technology through industrial "partnering facilities" that are well established and proven
- Lead the Nation's efforts in industrial cyber security and threat analysis, wireless communications spectrum utilization, grid reliability security and resilience, non-proliferation technology development, armor design and manufacturing
- Lead the integration of nuclear power plant safety, safeguards, physical and cyber security
- Play a key role in addressing our need for energy critical materials, lead the research in energy systems integration, hybrid energy systems, large-scale bio-mass feedstock assembly, vehicle and grid-scale energy storage



- Improve our understanding of technology choices in the context of policy, regulation and economics as well as a "system" perspective through enhanced analytical capabilities enabled through partnerships
- Play a larger role in the public discourse on the expanded use of nuclear technology and the linkages between nuclear energy, environmental and national security through regional relevance and effective public information and education.

Core Values

INL has four core values, which serve as a compass for our actions and describe how we best behave in the world in pursuit of INL's mission and vision.

John Grossenbacher
President and Laboratory Director

EXCELLENCE

We do our best work every day

INTEGRITY

We demonstrate honesty, professionalism and equity in every decision and action

OWNERSHIP

We take pride, accountability and responsibility for actions that drive laboratory success

TEAMWORK

We treat others with dignity and respect, and promote collaboration

Todd Allen
Deputy Laboratory Director
Science & Technology

Juan Alvarez
Deputy Laboratory Director
Management

Riley Chase
Deputy Laboratory Director
Nuclear & Laboratory Operations

Core Values

EXCELLENCE: *Dr. Laura Carroll strives to be the best she can be in several areas important to the mission of INL. She is the principal investigator for the "Fast Reactor Advanced Materials: Advanced Alloy Testing" project and is the task lead for the "Elevated Temperature Cyclic Behavior Characterization" portion of the Next Generation Nuclear Plant program.*

Dr. Carroll's work is key to developing new nuclear reactor designs and gaining their acceptance by the U.S. Nuclear Regulatory Commission. Arriving at INL in 2008, she has already made an impact to enhance INL's research capabilities and reputation. Through her hard work and commitment to excellence, Dr. Carroll was named recipient of INL's 2012 Early Career Exceptional Achievement award.

INTEGRITY: *Chris Hott, Director for Laboratory Performance, is building on recent efforts and achievements by Laboratory Performance to optimize and improve the effectiveness of contractor assurance and quality assurance activities at INL. His integrity, professionalism and honesty have emerged as key traits as he leads a change leadership team for the Lab to shift the contractor assurance paradigm from traditional assessment as the key means of evaluating performance.*

He routinely ensures key laboratory stakeholder input is obtained and built into the project team effort while optimizing and effectively implementing changes to contractor assurance processes and procedures. Anyone who works for Chris also knows that he has a strongly held sense of commitment to outcomes, equity in decisions and high standards in oneself.

OWNERSHIP: *By demonstrating the value of ownership and showing a willingness to exercise his right to call a Timeout, operator R.D. Sortor helped to prevent a violation of the Fuel Conditioning Facility (FCF) Technical Safety Requirements (TSR).*

Prior to starting a transfer, R.D. questioned whether the amount of water in a filter box would violate the limit for the zone into which it would be transferred. When notified, his foreman honored the Timeout and paused work until they could resolve the issue. They got all of the right people involved, including the FCF Criticality Safety Officer, INL Criticality Safety, and their upper management. It was determined that completion of the transfer would indeed have resulted in a TSR violation. R.D. displayed the sense of ownership INL seeks to instill in all of its employees.

TEAMWORK: *INL's triple threat trio – Mark Stone, the Principal Investigator Aaron Wilson, and Frederick Stewart – combined their team efforts to invent the Switchable Polarity Solvents Forward Osmosis (SPS FO) process to clean industrial waste water for reuse.*

As a result of their collaborative efforts and respect the trio has for each other, their accomplishments have received triple the recognition by earning the international 2013 R&D 100 Award, the Federal Laboratory Consortium (Far West) award, and the regional Idaho Innovation Award competition.

Translating INL's vision into reality is achieved through a distinct strategic course and organization that quickly sets INL apart from others. Three high level outcomes are vitally important for this purpose.

Lead Laboratory for Nuclear Energy

To achieve energy security and climate change program objectives, the U.S. must develop and deploy clean, affordable, domestic energy sources. Nuclear power is a key component of a portfolio of technologies that meets our energy needs. Key challenges to the increased use of nuclear energy include high capital costs of new large plants, safety performance, high-level nuclear waste management and concerns of nuclear weapons stemming from potential access to special nuclear materials and technologies.

As the preeminent, internationally-recognized laboratory in nuclear energy technologies (including advanced fuel cycles) INL is helping to resolve these challenges through:

- Engineering driven science-based approach to the development and performance of nuclear fuels and materials applicable to current and future generations of reactors
- Fuel cycle technologies including advancements in pyro and aqueous processing technologies, nuclear materials management and non-proliferation standards
- Reactor safety, material science, and human performance for life extension of light water reactors
- Advanced reactor design and optimization to achieve safe and economically advanced nuclear power plants
- Overwhelming commitment to safe operations and proper stewardship of the environment.

Leadership in National and Homeland Security

Threats posed by global terrorism, the proliferation of nuclear materials, and the vulnerability of U.S. critical infrastructure have continued to evolve in complexity. INL's isolated site, test bed infrastructure, and applied-science focus make it a major center for national security technology development and demonstration. Primary focus areas are:

- Detecting and preventing the spread of nuclear materials and providing emergency response training and technology RDD&D that strengthens international stability
- Protecting the nation's critical infrastructure from cyber attack, including improvements to the availability of wireless communications, and securing the resiliency of our national power grid
- Manufacturing improved armor capabilities used by the U.S. Army to protect soldiers' lives from explosives and other blasts
- Providing unique analysis and applied solutions to satisfy requirements for Defense and Intelligence Community customers.

Leadership in Clean Energy and Regional Integration

Energy resources concentrated along the Rocky Mountains and northern plains into Canada and the U.S. are rich in diversity and offer a foundation for additional energy solutions. As a multi-program laboratory with world-class clean energy capabilities, INL is working to provide a foundation for advancing development of these resources through:

- Science-based performance assessments for energy storage and bioenergy system potential for the U.S.
- Clean energy integration design, test, control, and validation to advance system design, planning and operation
- Energy critical materials research to develop material and technology substitutes.

Principles

INL philosophy is guided by five important principles

- We demonstrate world leading safety behaviors and environmental stewardship
- We identify national problems and apply our unique ideas and resources to create a novel solution
- We share our facilities as national assets
- We bring together people, facilities and expertise to solve national challenges
- We expect our staff to be international leaders who publish, publicize, and present as a means of establishing the laboratory legacy.

With these principles as the foundation, INL strategy focuses on developing technology for deployment through the use of capability that is unique to INL and described in three key mission areas. Details of the technical work in these key mission areas are included in Appendix A.

INL's Themes of Excellence

- The R&D directorates are individually successful and actively engage with other divisions to create synergistic discovery
- The three directorates and two major nuclear mission centers are aligned in vision and mission execution to properly allocate resources to assure success
- INL facilities are national assets for academia and industry users' applied RDD&D
- Support organizations and laboratory processes are aligned with mission success
- Laboratory success is measured by simultaneous excellence in mission, operations, and community service.

Expectations

INL will lead the Nation in stimulating intellectual excitement and facilitating innovation in nuclear energy technologies by:

- Administering a well-focused highly-productive NE university program
- Expanding the next generation of partnerships using ATR National Scientific User Facility (ATR NSUF)
- Modeling and simulation that is domain-centric and facilitates collaborations
- Knowledge Centers that make data, experimental and modeling insights widely accessible
- Enabling encouraging and often leading impactful outcome oriented research with industry, the NRC, National Labs, Universities, and International partners
- INL will help educate and develop the next generation of nuclear scientists and engineers with its intellectual leadership, materials, large-scale facilities, modeling and simulation tools, data, partnerships and experimental know-how.

Core Missions of the Lead Nuclear Laboratory

As the nation's lead nuclear energy research laboratory, the core missions are the top priority research programs at INL. These programs are designed to inform and provide options that will enable the federal government and industrial decision-makers to set policies and create nuclear energy initiatives that are strategic and sustainable. These priority research missions include the following. (Described in more detail in Appendix A)

- Advanced Safety Methods
- Fuel Science
- Fuel Storage Science
- Global Threat Reduction
- Grid Modeling and Simulation
- Hybrid Energy Systems
- Nuclear and Radiological Activity Center
- Safeguards and Security by Design
- Signatures and Observables
- Space Nuclear Systems and Technology
- Training and Response
- Transient Testing Science Program
- Validation Center for Application-focused Modeling and Simulation.

Security and Clean Energy Missions Tied to Unique Idaho Facilities

INL provides unique capabilities, facilities, and expertise that complement the lab's nuclear mission. Non-nuclear strategic research programs are used to provide applied energy engineering research capability to assist the U.S. in achieving environmentally responsible energy security and are grounded in unique Idaho capabilities. Emphasis is placed on advancing deployment of technologies that enhance clean energy development, delivery, security, and use, and address management of energy-related materials and environmental consequences. Strategic non-nuclear missions tied to unique INL facilities are listed below and described in more detail in Appendix A.

- Advanced Transportation Systems
- Bioenergy Programs
- Clean Energy Integration and Systems Security
- Defense Systems Specific Manufacturing Capability
- Industrial Control Systems Cyber Security
- National University Consortia (NUC)
- Regional Leadership: Center for Advanced Energy Studies (CAES)
- Wireless Test Bed and Grid Integration.

Security and Clean Energy Missions where INL is a National Leader

INL has been a major contributor to nuclear energy, national and homeland security and clean energy technologies for over 60 years. INL has leveraged its scientific expertise, engineering discipline and unique infrastructure to become a national leader in developing defense, homeland security, energy, and use industry solutions. To maintain momentum and benefit to customers, core non-nuclear missions or strategic research programs where INL is a national leader are as follows, and are described in more detail in Appendix A.

- Critical Infrastructure Protection
- Critical Materials Institute – An Energy Innovation Hub
- Critical Systems Vulnerability Analysis
- Cyber Physical System Protection
- Instrumentation Control and Resilient Control Systems
- Industrial Control Systems Mission Support Center
- Natural Gas
- Water Security Test Bed
- Wind and Geothermal.

People

People

Leadership-class research, safe operations, and management talent is the foundation of INL; enabling this talent to succeed in making sustained national impact in the areas we have chosen to engage, in the most efficient and effective manner possible, is foundational to INL success.

This philosophy guides all that we do at INL, and developing innovative approaches to put this philosophy in action is an ongoing priority of the Lab. The national laboratory of the future will need to be innovators in talent development based on highly efficient multi-institution collaboration, strategically aligned and focused partnerships, and impactful coupling of research teams and infrastructures. This is the focus of our education and university outreach programs at INL. (These are also challenges we must address to allow our people to make the greatest impact throughout their careers.)

LEADERSHIP-CLASS RESEARCH, OPERATIONS, AND MANAGEMENT TALENT IS THE FOUNDATION OF INL.

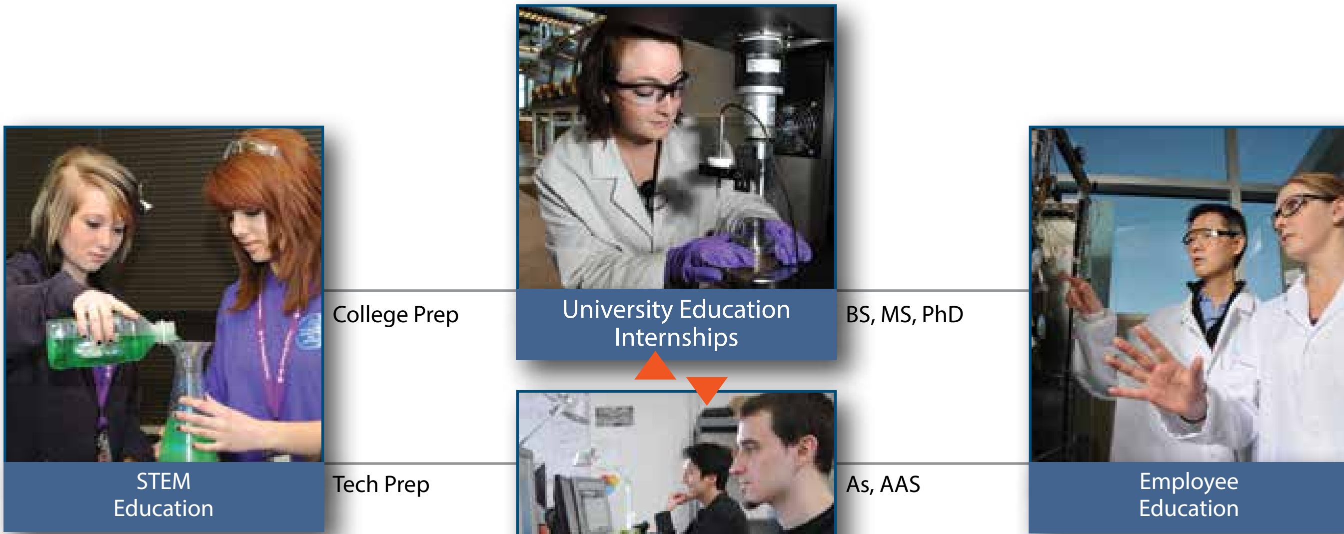
INL researchers test new, more intuitive digital control room displays in a virtual nuclear control room called the Human Systems Simulation Laboratory.

THE NATIONAL LABORATORY OF THE FUTURE WILL NEED TO BE AN INNOVATOR IN TALENT DEVELOPMENT, STRATEGICALLY ALIGNED AND FOCUSED PARTNERSHIPS, AND IMPACTFUL COUPLING OF RESEARCH TEAMS AND INFRASTRUCTURES.

Critical elements of our talent development approach include the following.

- Finding better and more effective means to continually attract top talent in a strategically focused manner
- Institutionalizing leadership-class training and development for all employees
- Implementing continual and sustained recruitment based on key research partnerships and collaborations
- Accommodating changing workforce philosophies, attitudes, demographics, and mobility
- Allowing for greater professional mobility and change
- Cementing our role as a recognized regional and national resource in our strategic focus areas.

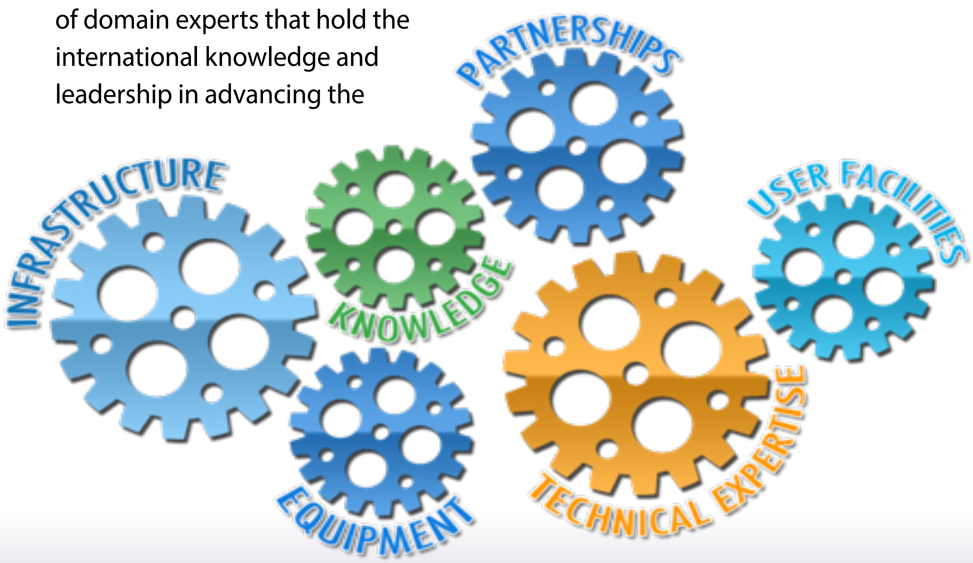
At the local and regional level, INL is committed to helping our education leaders improve the quality of K-12 learning. We are committed to enhancing science, technology, education and mathematics (STEM) programs in particular, and enhancing the diversity of students pursuing STEM education, where we invest Laboratory funds to substantial leverage with government and private sector funds to create impact. Our commitment goes on to include novel post K-12 opportunities, including vocational technical training targeted to critical aspects of the energy and security markets, investment in our own employees' continuing education, and other novel workforce development programs.



Our approach to university outreach and partnerships is particularly important for the near- and long-term success of the Laboratory. University outreach is embedded in each of INL's core mission areas, and enabled by Laboratory investments and expertise. Key to our success is our ability to strategically focus on developing and maintaining important university partnerships tied to our mission focus while maintaining a broad national and international reach to attract the best and brightest researchers and partners. Regional universities also have a special role in our talent development strategy, as embodied in the CAES. Characteristic of INL talent development approach, our CAES collaboration will be increasingly embedded in the mission organizations of INL and will mature into an industry and regional portal for the Laboratory.

Capabilities

Important to the success of INL is the deployment and implementation of critical capabilities, or the facilities, tools, systems and technology that become international standards. These tools are backstopped by a set of domain experts that hold the international knowledge and leadership in advancing the tools and assisting users from around the world in furthering research goals through the continued expansion of their use. Examples of such critical capabilities include the MOOSE modeling framework, the RELAP nuclear safety code, the advanced vehicle battery testing capability, and the Sophia industrial control systems monitoring software described in Appendix A.



Facilities

Facilities - The User Facility Model

INL is a critical hub for performing RDD&D. Excelling in our mission requires the ability to connect vitally important INL facilities to INL staff as well as national and international industry, university, and other national laboratories.

INL runs three major user facilities open to the international community, The Advanced Test Reactor National Scientific User Facility (ATR NSUF), the Wireless National User Facility (WNUF), and the Biomass Feedstock National User Facility (BFNUF). Descriptions of these user facilities are in Appendix B.

The benefits of the user facility concept are:

- Easy access to nuclear and radiological facilities by domain experts
- Access to research quantities of special nuclear material
- Optimum use of infrastructure investments without unnecessary duplications
- Industry access to expensive facilities for rapid commercialization
- Training of the next generation of nuclear engineers and scientists.

INL will engage the international community as necessary to supplement INL user facility capabilities and form the right team to develop and deploy critical technologies. Similarly, INL staff will pursue research goals by using INL-based and/or other national or international capabilities – e.g., using the right tool as necessary.

Conducting RDD&D

Through our values, principles and themes of excellence, INL is the national capability hub for a successful RDD&D campaign that is meeting and helping to solve the nation's nuclear energy, energy supply, environmental and energy security needs. This is accomplished by weaving INL's RDD&D capabilities, knowledge centers and unique shared facilities with technological accomplishments. We maximize our scientific impact and contributions through an exceptional R&D work experience and partnering as needed with universities, other laboratories, and industrial organizations to develop and continue developing advanced solutions. This combination of intellectual leadership, domain expertise, key facilities, capabilities, historical data, and modeling tools provide the stewardship for national nuclear energy research programs.

The successful framework of RDD&D conducted by INL is supported by pride, accountability and responsibility in maintaining the key facilities that are shared as national assets, and honesty, professionalism and high standards embedded in our knowledge centers and collaboration tools. Through the effective combination of people, facilities and expertise, INL is respected and regarded by our stakeholders and staff as a renowned RDD&D institution – attracting the talent, capital and cooperation needed to expand our scientific impact, inform the national agenda, and achieve our mission outcomes.

WE MAXIMIZE OUR SCIENTIFIC IMPACT AND CONTRIBUTIONS THROUGH AN EXCEPTIONAL R&D WORK EXPERIENCE

RDD&D Needs

- Industry
- Regulator
- Government

RDD&D Capabilities

- Universities
- Laboratories
- Industry Partners
- Regulator
- Government Agencies

INL Enabled Partnerships and Collaborations Through:

- User Facilities
- Knowledge Centers
- A Collaboration Enhancing Modeling and Simulation Environment

INL - The National Nuclear Energy Laboratory

- Intellectual Leadership
- Domain Expertise and Knowhow
- Facilities
- Materials
- Historical Data, Modeling and Experimental Insight
- High Performance Computing
- Ownership/Stewardship of DOE-NE Program

Advancing nuclear energy RDD&D solutions and informing energy policy to enhance U.S. economic competitiveness, energy security, and environmental quality requires INL to exhibit a robust model of leadership both regionally and internationally. This includes three major areas listed below.

Advancing data driven energy and science policy and systems analysis

- Provide leadership on the national nuclear energy and energy security policy agenda
- Build strategic partnerships with the private sector, universities, and others to increase investments in RDD&D innovation
- Assist DOE in leading international and intergovernmental dialogues on nuclear energy
- Provide leadership in broad platforms for regional cooperation on energy, focusing on major economies and key partners
- Increase engagement with state, local, and tribal governments on matters of energy policy, technology and resources.

Building workforce capacity to meet future DOE mission needs

- Develop employees and leaders in line with mission needs
- Increase quality and efficiency of human resource processes and policies
- Improve employee engagement and accountability for achieving the mission
- Promote diversity.

Conducting mission strategic planning

- Identifying new markets, capabilities and assets that will give INL a competitive edge
- Documenting and measuring progress in realizing the Laboratory vision/mission
- Establishing and maintaining long-term partnerships/ relationships with private industry and the scientific and local communities
- Communicating effectively with DOE, other countries and stakeholders
- Understanding, management and allocation of the costs of doing business
- Utilizing corporate resources to establish joint appointments or other programs/projects/ activities to strengthen the Laboratory
- Advancing excellence in stakeholder relations to include good corporate citizenship within the local community.

Idaho Governor's Leadership in Nuclear Energy (LINE) Commission outlines recommendations for INL.

Location:
Idaho Falls, Idaho

Type:
Multi-Program Laboratory

Web Site:
http://www.inl.gov

Contract Operator:
Battelle Energy Alliance, LLC

Responsible Field Office:
Idaho Operations Office

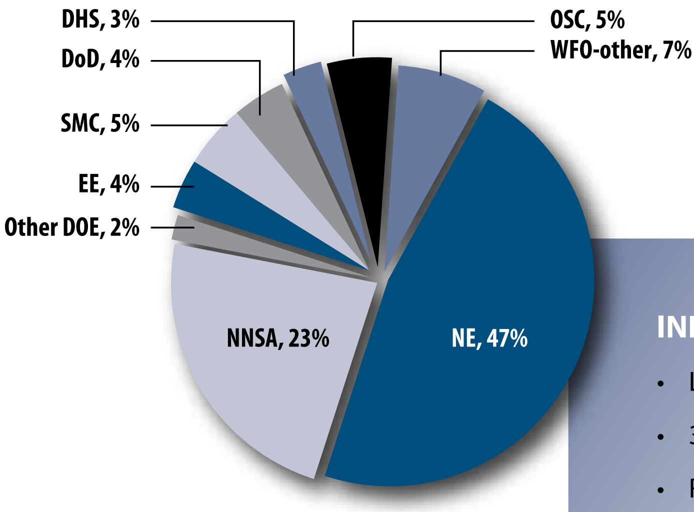
Site Manager:
Richard Provencher

Research Metrics (FY13)

INVENTION DISCLOSURES	32	94	NEW LICENSE AGREEMENTS
U.S. PATENTS FILED*	NINETEEN	THIRTY NINE	U.S. PATENTS ISSUED*
COPYRIGHT ASSERTION GRANTED	21		NATIONAL/ INTERNATIONAL AWARDS
VISITING FACULTY	ONE		
INTERNS	154	17	NEW SCIENTIFIC & ENGINEERING HIRES
POST DOCS	EIGHT	FORTY	STUDENTS
REFEREED PUBLICATIONS	211	4	STEM-12 TEACHERS

Includes patents filed or issued to DOE based on inventions from INL inventors.

Business Volume by Source ($M)



INL's Total Owned and Operating Assets:

- Land area: 890 square miles
- 327 buildings
- Research quantities of high-value special nuclear material
- Replacement plant value: $4.7B
- Large investment in high-quality safeguards and security program to make materials and facilities available for research.

Summary

Our identity is the National Nuclear Energy Laboratory. Together with world-leading programs in national and homeland security and clean energy development we focus on and make available unique Idaho facilities to solve complex technical challenges. Key to our success is the people who lead programs, with insight into the regional, national, and international environments, which solve key industrial and governmental challenges.

PREEMINENT INTERNATIONALLY-RECOGNIZED NUCLEAR ENERGY RDD&D LABORATORY

- Develop world-class nuclear energy capabilities
- Major center for national and homeland security technology RDD&D
- Foster education, research, industry, government and international collaborations
- Lead laboratory and regional resource for clean energy systems RDD&D
- Exhibit world leading safety behaviors and environmental stewardship

Most of INL's R&D capabilities are focused and located at three primary laboratory areas.

Mission Area 1: Core Missions of the Lead Nuclear Energy Laboratory

Advanced Safety Methods

The unfortunate events in Fukushima resulted in a fresh look at the quantification of the safety margins in existing nuclear plants and evaluation of potential additional defense-in-depth measures. Deterministic and probabilistic safety analyses are required to evaluate the lessons learned from Fukushima.

Recent improvements in nuclear energy modeling and simulation make advances in safety analyses methods possible. Using state-of-the-art computational methods such as those used in the MOOSE framework, coupling multiple physics at different scales is possible. This multi-physics, multi-scale approach, in turn, enables the development of best-estimate predictive models to replace the current safety analyses codes that are of 1980's and 1990's vintage. The current codes are not computationally efficient in today's standards and are limited in their capability of incorporating mechanistic models at different time- and length-scales, and often relies on providing bounding, conservative estimates based on empirical observations. Bounding estimates are not very useful for risk informed decisions, as the risk estimates can be considerably exaggerated. Different codes apply to different phases of an accident scenario and they cannot be easily coupled. Furthermore, uncertainty propagation techniques are difficult to apply. Finally, the computational efficiencies of modern platforms (such as MOOSE) enable the coupling of probabilistic and mechanistic analyses resulting in efficient calculation of risk.

Using a MOOSE based framework approach, a modern set of safety analyses tools can be created fairly quickly. Models describing different physical phenomenology at different scales can be developed almost independently by the domain experts (at multiple laboratories and universities) and coupled together to investigate the overall system behavior. On the other hand, considerable validation of these tools will be required before they can replace the existing codes that are repositories of tremendous knowledge from decades' worth of expensive and complex experiments.

Fuel Science

Development and qualification of new nuclear fuels is an expensive and lengthy process. From concept to commercial deployment, the process typically takes 20 to 25 years and on the order of hundreds of millions of dollars (depending upon the complexity of the concept). The length of the development period and the cost are primarily due to expensive and iterative testing required when using an Edisonian approach. Each cycle of testing include fabrication processes, characterization, out-of-pile testing, in-pile testing, post-irradiation examination (PIE) starting with laboratory scale and progressing towards commercial scale. With advances in material science and computational methods, an engineering driven science-based approach can be used to develop fuels that meet the performance and safety requirements with a smaller number of prototype tests.

The elements of the engineering-driven science-based approach include multi-scale, multi-physics modeling of fuel performance that includes phenomenological models at different length and time-scales. These models need to be validated at those various scales; thus, requiring state-of-the-art characterization and PIE techniques. Most of the equipment for this purpose exists for non-nuclear applications but part of this initiative would be to adopt these measurement techniques to highly radioactive nuclear fuel samples. Finally, the ability to conduct integral effect and separate effect irradiation experiments with advanced in-situ instrumentation is another critical piece of the fuel science initiative.

Fuel Storage Science

Extended storage and subsequent transportation of Used Nuclear Fuel (UNF) is of major interest to the sustainability of nuclear energy in the near term until a permanent solution in the form of final disposal is available. The long-term (~100 years) safe and secure dry storage and transportation of UNF of all kinds discharged from different power plants are of interest but the near-term emphasis is on high-burnup fuel storage (≥ 45 GWd/t). DOE-NE is just starting a full-scale demonstration of extended storage of the high-burnup fuel. While the full-size demonstration will provide valuable data for licensing, its full benefit can be realized if it is coupled with an engineering-driven science-based approach aimed at a fundamental understanding of the fuel and cask behavior along with predictive modeling.

The engineering-driven science-based approach includes (a) separate effect testing (mostly mechanical and chemical properties) of fuel and cladding samples obtained from fuel elements, (b) small-scale experiments with continuous access and advanced instrumentation located in a hot-cell, and multi-scale, multi-physics modeling of the cask and its contents (combined with an uncertainty propagation methodology). Along with the MOOSE based virtual cask models, INL has the capability to perform the separate effect and small-scale tests. Once the irradiated fuel elements are cut into smaller samples, separate effects testing and characterization capabilities also can be used to complement INL capabilities.

In addition, the demonstration project requires a facility where the full cask can be opened at given intervals (5 to 10 years) to examine the contents and to compare the data with the results of the predictive models. When the cask is open, non-destructive exams as well as destructive exams on collected fuel elements can be performed. The preferred way to open the cask would be in a dry facility (as opposed to opening under the pool and re-drying the contents after the examinations).

Global Threat Reduction

Nuclear and radiological materials exist in numerous locations throughout the world, many of which are not adequately secured. The threat can be reduced by removing materials to more secure locations, dispositioning or replacing the materials in a way that makes them less of a threat, and enhancing protection for materials that cannot be removed or dispositioned.

INL will continue to develop and deploy nuclear fuels that are inherently proliferation resistant, building on development of low-enrichment fuels to replace highly enriched fuels, and providing needed technical support for reactor conversions. As new reactor designs are deployed to address future energy needs, proliferation resistance and security will be incorporated at the front end of the design process. INL will also leverage expertise in international program management to continue to remove nuclear materials globally to more secure locations and to support security enhancements in locations in which these materials reside.

Grid Modeling and Simulation

A twenty-first century economy requires a modern electric power grid that can effectively utilize renewable energy sources, distribution generation, and demand response programs, while accommodating plug-in hybrid electric vehicles and other energy-efficient technologies. Additional capacity is needed to meet growing electricity demand, and smart grid technology is needed to enable the two-way flow of electricity and information. All of these significant grid modernization efforts need to be integrated while increasing reliability and resilience of our nation's power grid. The INL hosts a suite of modeling and simulation tools to study the potential impacts these new technologies will have on our power grid. At the top of the tool set, the Real Time Digital Simulator, or RTDS provides power systems simulation technology for fast, reliable, accurate, and cost effective study of power systems with complex High Voltage Alternating Current (HVAC) and High Voltage Direct Current (HVDC) networks. The RTDS simulator is a fully digital electromagnetic transients power system simulator that operates in real time. Real-time simulation is significant for two reasons - the user can test physical devices and the user is more productive by completing many studies quickly with real-time simulation. The ability to simulate real-time power grid dynamics is a key factor in detecting previously unknown vulnerabilities and providing emergency planners with a path forward for responding to grid failures. Hybrid Energy Systems Achieving the national objective of 80% of U.S. electricity coming from clean energy sources while maintaining affordable, secure, and resilient energy systems is a grand challenge at the heart of U.S. energy security strategy. An "all of the above" approach – growth in renewable, nuclear, and carbon-based energy deployment – is necessary to achieve this aggressive goal. Increasingly, then, these discrete energy conversion processes will need to be integrated and optimized in significantly more complex and interactive power systems, or "hybrid" systems. Hybrid energy systems offer opportunities to solve key impediments to clean energy integration, including grid stability, expanded use of nuclear energy, renewable energy systems capacity factor (economic performance) enhancement, and cleaner carbon conversion systems. INL is a national leader in energy systems integration, with capabilities in the area of energy conversion systems design, resilient controls, advanced modeling and visualization, and systems (conversion, mechanical, and grid) testing.

Nuclear and Radiological Activity Center (NRAC)

In 2013, INL established the Nuclear and Radiological Activity Center (NRAC). NRAC provides a suite of capabilities tailored to nuclear nonproliferation and global nuclear security to a wide variety of customers, including industry and academic users. Ready access to special nuclear materials and radiological sources in venues that support research, technology demonstration, and training is a central part of NRAC. Dedicated facilities (e.g., Zero Power Physics Reactor - ZPPR facility) and test ranges (e.g., Radiological Response Test Range) are provided to support research, demonstration and training in real-world environments.

Safeguards and Security by Design

Safeguards and security for fuel cycle processes and facilities must be enhanced such that diversion of materials is difficult to achieve, and yet easy to detect. Theft or sabotage must be unlikely, requiring a continuous effort to identify and address emerging threats. As new and advanced fuel cycle processes are developed and deployed, safeguards and security must be designed in and integrated in ways that do not interfere with safe and efficient operations. New methods for optimizing nuclear safety, production, safeguards, and security must be developed and deployed to achieve resiliency.

INL will develop and deploy safeguards approaches that go beyond material accountancy. Next generation fuel cycle facilities will bring new challenges to diversion detection. Material accountability will be supplemented by analysis and authenticated elimination of diversion pathways in the design phase, and implementation of real-time process monitoring to supplement and improve upon the timeliness of diversion detection. INL leads development of holistic approaches to nuclear security by merging core capabilities in vulnerability assessment and cyber security. INL will leverage world-leading expertise in both design basis threat and risk-based assessment of nuclear safety to develop and apply methods for optimizing nuclear safety, production, safeguards, and security.

Energy for

The National Nuclear Energy Laboratory

Mission

Proving the Principle of National Energy and Security Solutions using World-class Capabilities

Vision

To sustain core technic
and develop innovative
secure and advance nu
clean energy choices fo

the Future

al capabilities
e solutions that
clear and other
or our future

Values

Excellence • Integrity • Ownership • Teamwork

Idaho National Laboratory

Signatures and Observables

Detection and identification of unsecured nuclear and radiological materials and illicit activities requires the ability to recognize characteristic signatures and observables. These may be associated with the materials themselves, or the activities and processes that may be employed to use these materials in weapons of mass destruction (WMDs). In many cases, only trace quantities of materials may be present for detection, and illicit activities and processes may be detected only through tertiary indicators. Forensic methods must be developed and deployed to aid in the identification of sources of weapons of mass destruction. Improved detection systems must be developed and deployed against evolving threats. Standards and reference materials, often not readily available, must be produced and made available to validate signatures.

INL will continue to develop the equipment and techniques that further push the capabilities of trace detection. Capabilities in mass spectroscopy equipment and methods development will be leveraged and grown to allow for detection of proliferate activities with greater sensitivity and from greater distances. INL will continue to investigate and validate alternative, indirect signatures of proliferation and illicit activity towards the development of WMDs and will support the production of standards and reference materials for nuclear and radiological forensics.

Space Nuclear Systems and Technology

INL is actively engaged in all aspects of providing power systems for operation in remote and harsh environments. These systems can take the form of passive conversion systems as used by The National Aeronautics and Space Administration (NASA) for space missions, such as the ongoing missions to Pluto (Pluto New Horizons) or Mars (rover Curiosity), or active systems such as small reactors that could be used for propulsion to places like Mars or for lunar applications. This has been an active area for the laboratory since 2002 when the national radioisotope power system program transferred the fueling and testing capabilities for radioisotope power systems from Mound Laboratory to the Materials and Fuels Complex. This mission has led to the laboratory supporting three NASA missions: Mars Exploratory Rovers (2003), Pluto New Horizons (2006) and Mars Science Laboratory (2011).

The laboratory's leadership in this area led to it being named as the Technical Integration Office for DOE's Space and Defense Power Systems in 2012. New power systems are being developed by DOE for NASA and the laboratory plays an active role in this area. The newest power systems may increase the power conversion efficiency by a factor of four over legacy systems which would be of great interest to users such as NASA where power to weight ratios are of much interest.

The laboratory is also an active partner with Oak Ridge National Laboratory in re-establishing domestic production of Pu-238 which is the heat emitting isotope used by all current radioisotope power systems. The production of Pu-238 lapsed in the United States of America in the late 1980's and is not produced anywhere else in the world.

Training and Response

The nation's responders must have technologies that allow them to address threats and must be proficient in the use of these technologies. The technologies need to be demonstrated and proven. WMDs must be accurately characterized and disabled. Illicit activities and processes must be safely and effectively shut down. Proficiency must be gained through practice against representative challenges in realistic settings.

INL will continue to provide and expand full-scale immersive evaluation and training to the nation's emergency first responders and to the Department of Defense (DOD). INL's expertise, expansive site, nuclear and radiological facilities, and ready access to nuclear and radiological materials make the Laboratory a preferred provider for training of first responders. End users directly benefit from access to INL scientists and subject matter experts. INL will leverage this interface to improve the tools and techniques available to first responders, and to provide these improvements in integrated response systems.

Transient Testing Science Program

One of the major gaps associated with development of advanced fuels, worldwide, is the transient testing capability. The DOE-NE program is investigating the resumption of transient testing in the U.S. and the restart of the Transient Reactor Test Facility (TREAT) reactor at INL is being evaluated as an option. In addition to the reactor restart, the scientific support for transient testing also needs to progress in parallel. The scientific and engineering tasks include the experiment design and instrumentation, modeling and simulation associated with transient testing, and pre- and post-irradiation examination of the experiments. Transient tests are not only essential for qualifying advanced fuel concepts for deployment (via safety margin quantification and failure modes determination), they can also provide valuable fundamental data in support of the engineering-driven science-based approach for fuel development (see fuel science initiative). Having state-of-the-art transient testing capabilities also provide the U.S. with a prestigious position at the negotiating table for international collaborations. If the DOE proceeds to restart TREAT, it will be used as part of the user facility concept (see ATR NSUF).

Validation Center for Application-focused Modeling and Simulation

As discussed in the previous sections, the engineering-driven, science-based approach relies heavily on multi-scale, multi-physics predictive modeling. Engineering-scale, or commodity computing, is fundamentally different. Using object-oriented modern computational platforms, such as the Multiphysics Object Oriented Simulation Environment (MOOSE), the modeling tools for the simulation of the nuclear energy systems and its components during normal operations and accident conditions can be developed fairly easily as physics modules. However, for the nuclear energy applications of interest, such models would be useful without an excessive validation process.

The new multi-scale, multi-physics predictive codes require new fundamental data for validation, especially at lower length scales. However, the bulk of the validation will have to rely on historical integral data collected over many decades through expensive full-, semi- or small experiments. Duplicating this database would be cost prohibitive. Mining, storing and re-synthesizing these data within the context of the multi-scale, multi-physics modeling perspective are essential for the successful validation of the new tools.

Mission Area 2: Security and Clean Energy Missions Tied to Unique Idaho Facilities

Advanced Transportation Systems

Accelerating the introduction of electric vehicles (EV) that are cost and performance comparable to today's gasoline powered vehicles is a major part of the U.S. clean energy grand challenge and the U.S. strategy to address and adapt to climate change. The "EV Everywhere" challenge is a national effort to achieve clean energy security by addressing advanced transportation challenges through reduction of vehicle costs, reduction in battery systems costs, enhanced systems performance, and predictability of performance. INL is a major resource in this effort.

Founded on science-based performance analysis fundamentals key to our nuclear energy missions, INL has developed leadership-class capabilities and programs for analysis of advanced vehicle performance and analysis of energy storage device performance under varying conditions. Fundamental expertise in materials, chemistry, and mechanical systems performance, combined with expertise in testing program protocols and advanced data analytics provide the expertise base to model, analyze, and improve performance in these systems.

Key assets at INL also include world-class battery testing facilities that house environmental chambers, mechanical testing devices, chemical synthesis laboratories, materials characterization labs, electrical testing equipment, and computational simulation assets. INL will continue to deploy these capabilities as a national testing asset while expanding our work in the area of performance diagnostics and prognostics, advanced charging methods, and energy storage systems modeling for performance assessment. These capabilities will also be combined with our energy systems and transmission capabilities to design and analyze grid-scale energy storage systems, and develop more secure and resilient storage and charging systems.

Bioenergy Programs

The DOE Biomass Program has shaped the vision of a national, commodity-scale feedstock supply system. Much progress has been made in developing and reaching this vision through optimizing biomass logistics - and defining commodity attributes compatible with existing commodity-scale, solids-handling infrastructure. INL Bioenergy Program's mission is to accomplish a national transformation into renewable and abundant biomass resources through cost-competitive, high performance biofuels, bioproducts, and biopower.

The Bioenergy Program at INL is focused on transforming biomass from raw forms to customized feedstocks that are optimized for specific conversion processes. INL Bioenergy Program areas include feedstock supply system design and analysis, modeling and analysis of harvesting, collection, and storage systems, and preconversion of advanced feedstocks for bioenergy commodity markets. INL feedstock preprocessing research and development ranges from laboratory-scale applied science, to bench-scale prototyping, to pilot-scale testing and demonstration. INL's program is now housed in the new BFNUF located at INL's new Energy Systems Laboratory (ESL); one of the premier facilities in the U.S. for scientific and technical investigation of biomass feedstock evaluations, preparation, and investigation for transforming biomass feedstocks in support of biomass based energy security applications.

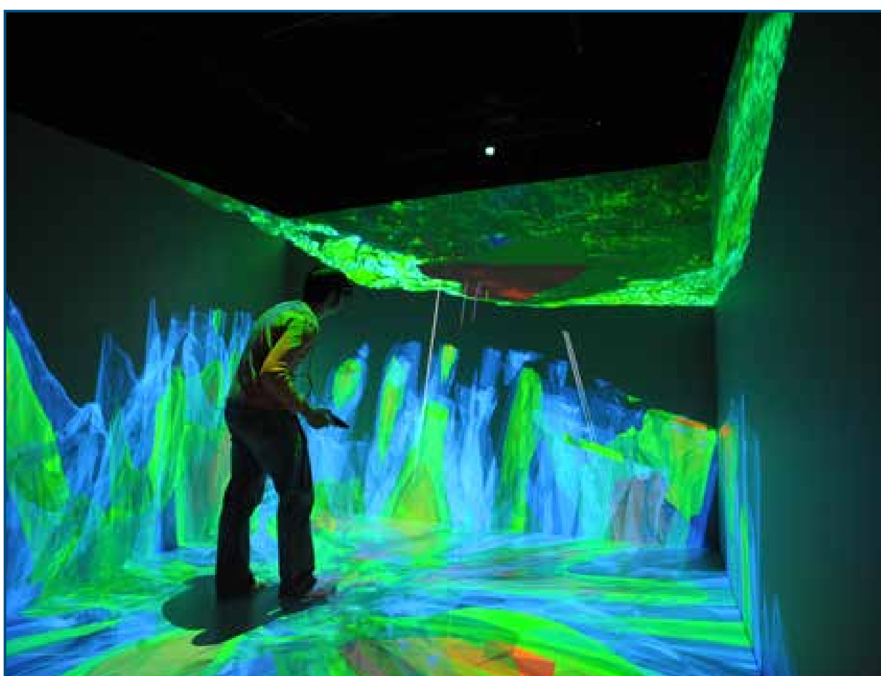
INL manages the DOE-funded Feedstock Process Demonstration Unit (PDU), a flexible pilot-industrial-scale research system for testing feedstock formulation processes, collecting process data, and producing larger quantities of formulated feedstocks for conversion testing. This system, in conjunction with the Biomass Resource Library and characterization laboratories at INL, enable bioenergy developers to test preprocessing technologies and advance feedstock engineering into the development phase.

Clean Energy Integration and Systems Security

Aggressive clean energy integration is a major tenant of the U.S. clean energy grand challenge, as well as central to U.S. strategy in addressing climate change issues. Key to meeting the goal of producing 80% of U.S. electricity from clean energy sources by 2035 and accelerating deployment of electric vehicles are integration challenges with the electric grid. The challenge is to progressively establish a resilient and secure tightly coupled system of distributed and dispatchable power generation and power management assets that accommodate a high penetration of variable/renewable resources and energy storage/buffering units, including interactive power consumers/producers. Optimization and integration of a significantly more complex and interactive power system requires not only new technology (e.g., sensors, controls, data communications, dynamic data/systems analysis software, and power electronics) but new approaches to integrated transmission and distribution planning and operations, renewable power generation, grid demand forecasting, and dynamic hybridization with energy storage options that will enable greater flexibility, higher systems efficiency, and increased profitability across the energy system.

INL has unique simulation and physical capabilities that address key research challenges associated with clean energy systems integration and the grid dynamics challenges that result. These resources (computational, analytical, and grid-scale testing) coupled as a national capability will be further developed and deployed to advance DOE and industry efforts to develop robust and efficient clean energy systems and assure electrical grid stability.

- **Computational and simulation tools for modeling complex energy systems** - following a structured approach that addresses; (1) systems assessment based on defined requirements, (2) technical/economical/environmental analyses that involve detailed plant design, optimized mass and energy integration, capital and operating costs estimates, discounted cash flow/net present value economic calculations, and life-cycle environmental sustainability assessments, and (3) dynamic energy system integration tools that are key to design, performance evaluation, system design optimization, and development and application of monitoring and controls and information management software for tightly coupled systems. A library of models has been developed for most common U.S. chemical and fuels synthesis plants and power generation facilities. Dynamic modeling is being completed with open-source, object-oriented programming tools to facilitate research collaboration with other labs, universities, and industry.



- **Energy systems research complex** - that includes newly constructed user test facilities: ESL; Research and Education Laboratory (REL); CAES; and National and Homeland Security (NHS) research buildings. These facilities are approved for collaborative industry research, development, and demonstration of new concepts, new equipment, and process instruments and controls. The ESL will host a micro-grid with representative power generation, power converters, electricity loads, and energy storage units. This will support renewable power generation characterization and development of dynamic energy storage devices such as electrical vehicle charging and discharging technology, and high temperature thermal energy storage and recovery. INL also proposes to demonstrate dynamic delivery of heat and electricity to an integrated manufacturing industry, such as a transportation fuels synthesis plant. The test activities will also provide the critical infrastructure and data needed to validate the simulation tools for process scale-up and codes for licensing.
- **60 mile, 138 kV, industrial-scale test grid loop** - with isolation capability to test power monitoring instruments and power management equipment located at substations in the loop and in concert with transient loads at INL operational facilities.
- **Real-time digital power simulation and modeling facility** - one of the largest in R&D environments used for real-time power systems modeling, cyber security, and power resiliency studies both in real-time as Hardware-in-the-Loop/ Controller-in-the-Loop and offline modes, for power management software development, and most importantly for model validation using real time “real world” environment. This is a critical tool for rapid prototyping of new energy systems hardware and control algorithms and for testing them in “real world” test environments. INL supports the Department of Homeland Security (DHS) and commercial industries with electric grid and process control systems cyber security evaluations.

Defense Systems Specific Manufacturing Capability

INL will continue to create and test innovative protective and armor materials and composites that are saving soldiers lives in battle for the U.S. Army using innovative processes. These methods have proven to be effective against physical threats to armored military vehicles and critical infrastructure components such as armor-piercing projectiles, explosive fragments, and explosive blasts. INL advances in protective materials and facility design have improved survival of vehicles and facilities by advancing technology in absorbing explosive energy and fragmentation resulting in enhanced protection for personnel, special materials, and critical infrastructure systems. It is critical that INL continue to manufacture and deliver armor solutions to meet the requirements of the U.S. Army.

SMC is a U.S. DOE Hazard Category 3 nuclear facility that specializes in threat defeat and survivability solutions. Since 1984 SMC has been the lead manufacturer of armor packages for the U.S. Army’s Abrams Main Battle Tank. Located at the north end of the 890-square-mile INL Site, this 25-acre armor-manufacturing complex provides 320,000 square feet of secure floor space complete with state-of-the-art equipment and a knowledgeable and security-cleared workforce. Capabilities at the SMC complex include light and heavy metal rolling, metal fabrication equipment, in-house engineering and quality departments, a state-of-the-art metallurgical lab, and experienced manufacturing support crafts (e.g., electrical, mechanical, and landlord). Through the years SMC has evolved from build-to-print to design, test, and build.

With these extensive resources, SMC can provide independent technical evaluations and solutions to manufacturing, engineering, and material science challenges for a variety of programs and customers. The proven expertise of the workforce and an extensive infrastructure investment make SMC an essential manufacturing and engineering resource for the nation.

Industrial Control Systems Cyber Security

INL has established internationally recognized expertise in identifying and reducing vulnerabilities in industrial control systems (ICS) including supervisory control and data acquisition systems, distributed control systems and energy management systems. On a daily basis, this expertise prevents malicious attacks from disabling our nation's most vital systems, like communications networks and power grids. To support our continued leadership in ICS cyber security, INL will maintain a dedicated control systems and cyber security testing center, and manage federal programs such as the Department of Energy's National SCADA Test Bed and the Department of Homeland Security's Industrial Control System Cyber Emergency Response Team (ICS-CERT).

National University Consortia (NUC)

The National University Consortia consists of: Massachusetts Institute of Technology, North Carolina State University, Ohio State University, The University of New Mexico and Oregon State University. These five national universities partnered with INL to facilitate the nuclear energy research and development efforts. They continue to work closely with INL researchers to develop innovative far-reaching concepts to expand the capabilities and workforce of the laboratory. Together with CAES, they also provide a closely linked pool of talent from which INL can draw on to develop and train the next generation of nuclear scientists and engineers.

Regional Leadership: Center for Advanced Energy Studies

CAES is a highly successful public-private partnership that leverages capabilities and resources among Idaho's three public research universities, BEA, and DOE to facilitate clean energy research and advance the education and training of the next generation of scientists and engineers. CAES collaborators have built a state-of-the-art research center comprising over 45,000 square feet of research laboratory and office space located in the heart of the new INL campus.

The CAES facility includes hydrogen labs, advanced materials labs, imaging suites, radiochemistry labs, analytical instrumentation labs, chemistry labs, systems modeling, visualization/power wall, Computer Assisted Virtual Environment (CAVE), instrument shop/repair and office space. This collaboration and physical assets are a key part of INL research programs, including the ATR NSUF, in the areas of energy systems integration, advanced

nuclear fuels and materials, nuclear nonproliferation, resilient controls and security, and mitigating the environmental consequence of energy operations. The CAES partnership will expand the reach and impact of INL research, provide a key pipeline for talent, and an important mechanism for collaboration with industry and regional stakeholders.

Wireless Test Bed and Grid Integration

Future cyber-physical systems have unique requirements in information connectivity. These new systems will employ an ever-expanding array of wireless communication linkages that are not designed with fundamental cyber-physical mandates in mind. INL is researching, developing, and deploying solutions to future challenges in assured connectivity as well as government critical systems interoperability, and maintaining connectivity in challenging radio frequency environments. As recognized by public and private electric grid leaders, INL's combination of its 60 mile long, 138 kV electrical test grid and Real Time Digital Simulator provide a unique capability for full-scale testing, modeling and simulation of technology innovations planned to advance the efficiency, resilience and security of our national power grid. Additionally, the state-of-the-art wireless test bed provides a vital resource in which uniquely integrated wireless/grid research can be conducted.

Results from this research will provide more effective grid architectures, communication products and integrated designs as well as technical data to drive national policy on grid reliability and resilience, spectrum sharing, security, and assured communications standards. In addition, with the rapidly expanding use of wireless communications in the nation's power grid, and the increasing cyber threat landscape, our unique and distinctive assets posture INL as the only place in the nation where the nexus of wireless, power, and cyber RDD&D can be conducted at full scale.

Mission Area 3: Security and Clean Energy Missions where INL is a National Leader

Critical Infrastructure Protection

INL is recognized as the leader in identifying and mitigating industrial control cyber-physical system vulnerabilities and improving the resilience and survivability of U.S. critical infrastructure. INL organizes highly skilled, adaptable teams comprised of vendors, operators and security communities to quickly research and efficiently evaluate specific high-priority vulnerabilities both in-house and at critical infrastructure sites. The proven objective and overall goal from this approach is to discover and mitigate both real and potential, cyber and physical hazards to critical infrastructure systems prior to the manifestation of malware or an actual cyber event. Only with in-depth experience with cyber-physical systems, including control system engineering, communications, software security, vulnerability and threat analysis, and civil engineering specific to these critical control systems, can effective protection innovations be developed.

INL works today to discover, develop, and deploy innovations advancing integration of cyber and physical security of the nation's critical infrastructure systems. This RDD&D effort will continue to provide innovation to monitoring, detection, mitigation, and resiliency essential for physical and cyber protection of our U.S. critical systems. All critical infrastructure sectors will benefit from architecture enhancement, focused research, and tool deployment, including delivering improvements to the nuclear sector as INL is the National Nuclear Energy Laboratory. Key infrastructures such as the electric grid, oil and gas pipeline, communications, and manufacturing sectors will also be addressed given their importance to the U.S. economy.

Critical Materials Institute – An Energy Innovation Hub

A critical material is both essential in use and subject to supply restrictions. Manufacturers whose products depend on a critical material face risks with one or a combination of two consequences: (1) physical unavailability of a key input and (2) high or unstable input costs. A supply restriction or the threat of a supply restriction for a material critical to an emerging technology can stall the development and deployment of any technology. Three types of innovation can ameliorate this threat: innovation that (1) diversifies sources, (2) allows substitution away from a critical material (reducing its importance in use), or (3) reduces waste and/or increases recycling. Any of these innovations may expand the pipeline delivering materials into green energy technologies.

Innovation to diversify sources increases availability and reduces supply risk. It requires advances in process engineering and underlying science that together open up previously uneconomic mineral deposit types to commercial production, permit extraction and recovery from mine tailings.

INL is participating in the Critical Materials Institute (CMI), an Energy Innovation Hub, with eleven integrated (both nationally and locally) projects that draw upon our key competencies from across all three laboratory directorates, including separation sciences, electrochemical, and pyro-processing methodologies, supercritical fluid extraction methodologies, membrane science,

water treatment, and environmental impacts. The National Security Programs organization is supplying expertise in economic analyses that will develop validated predictive tools and materials databanks to assess and develop techniques to reduce environmental impacts, and to carry out supply chain and economic analysis. This activity will tie the evaluation of CMI R&D to market conditions and the degree to which the R&D facilitates reduced criticality. It also will guide decisions about reprioritization of CMI activities toward materials that may become critical in the future.

Critical Systems Vulnerability Analysis

To analyze critical system vulnerabilities, INL analysis centers are dedicated to developing unique methods for reducing the risk posed to our most critical cyber- physical systems. Particular attention is devoted to the critical systems found in our nation's infrastructure. Each center focuses on developing and applying unique science- and engineering-based analyses for identifying, validating, mitigating, and predicting both software and system vulnerabilities. In near-term support of this challenge, INL currently hosts ICS-CERT, assesses the security of control systems, develops leading edge tools for support of system cyber vulnerability monitoring and management, and is developing unique methodologies for identifying classes of software vulnerabilities.

Further, a critical system threat assessment capability includes evaluation of both foreign and domestic technical, scientific, and all source information. The assessment capability is used to monitor trends and advancements in cyber threats relative to possible system or software vulnerabilities in critical infrastructure. This concept melds intelligence analysis, cyber security expertise, and engineering experience to assess not only potential attack vectors, but also to analyze the potential impact of the future threat methodology and/or attacks. This information is vital to help focus the efforts of network defenders and program developers to remain ahead of potential threats.

Cyber Physical System Protection

INL will continue to protect National capabilities in cyber-physical systems, which require proper controls and facilities. Cyber-physical security threats have not been as prominent as information technology threats in recent media and threat assessments. Even though a cyber-physical attack is currently not as likely as information system attacks, the potential impact of a cyber-physical attack is far greater. The risk resulting from this level of visibility is that sufficient funding and multi-year support to provide executable, systems-wide protection will be more challenging to secure. Without effective programs, our nation's core infrastructures will be at risk and the expertise to provide protection against these risks will not be available. Additionally, effectively monitoring adversarial capability and developing innovative solutions to critical infrastructure threats requires work in, and access to, classified information agencies and channels.

Cyber-physical systems protection research and demonstration as well as a number of technology deployments from INL have had a direct impact on the nation's energy security and will become increasingly important.

INL has deployed a cyber security awareness and monitoring system called Sophia, specifically tailored to a national power grid control system. A result of INL's expertise in producing products to U.S. industry in a timely manner, Sophia direction addresses the Nation's cyber infrastructure challenges. Currently installed in 28 regional power distribution sites and licensed for use in 10 locations, Sophia enables cyber defenders to constantly monitor control networks and detect anomalous behavior. INL has also completed a first prototype of Net Muster, which provides radio frequency network modeling and simulation capability that bridges the gap between system design and real work execution and protection for complicated multi-network, cross-domain, high traffic-flow systems. INL has developed and published methodologies for the design, analysis, and validation for operation of complex resilient networks. INL's research in vulnerability prediction, discovery and mitigation may revolutionize how cyber vulnerabilities are categorized and managed. INL's methodologies to analyze cyber threats and threat actors are and will continue to provide guidance to intelligence agencies and cyber defenders on highest probability threats to defend against. Finally, INL's Multi-Carrier Spread Spectrum prototypes have demonstrated the ability to maintain wireless cyber-physical connectivity in highly jammed and spectrum challenged environments. This patent pending program was an R&D100 award recipient for 2012.

Future cyber-physical systems have unique requirements in information connectivity. These new systems will employ an ever-expanding array of wireless communication linkages that were not designed with fundamental cyber-physical security mandates in

mind. INL is researching, developing, and deploying solutions to future challenges in assured connectivity as well as government critical systems interoperability, and maintaining connectivity in challenging radio frequency environments. Results from this effort will provide more effective architectures, designs, and communication products as well as technical data to drive national policy on frequency allocation, security, and assured communication standards

Instrumentation Control and Resilient Control Systems

INL's continued programmatic research and development in instrumentation, control and intelligent systems (ICIS) is centered on developing components, programs, systems and individuals for any application that requires monitoring, control, security and human interaction. These capabilities have culminated in the development and deployment of cutting-edge, resilient systems. Resilient systems maintain state awareness and proactively maintain normal operations despite anomalies, such as malicious and unexpected threats.

The ICIS team developed the cyber security awareness and monitoring system, Sophia, highlighted below. The development of such technologies will usher in next generation designs for critical infrastructure systems, leading to a more stable and secure national infrastructure.

Advanced instrumentation and control systems require the development, design and implementation of programming and design innovation to both harden and provide resilience for cyber-physical systems. INL has begun to merge intelligent systems theory and algorithm development, combined with human factors research and failure path analysis to assist in stabilizing industrial control systems during an incident, such as a cyber attack. INL's continued development of new and resilient control systems, unique and revolutionary sensor detection methods, automation of supervisory control designs, autonomous action for defensive systems, and human-systems integration technologies for improving integration in the presence of advancing technologies will all have a significant positive impact in improving overall system resilience.

Industrial Control System Mission Support Center

INL established the Industrial Control System Mission Support Center (ICS-MSC) to address the nation's critical infrastructure protection cyber security challenges. The ICS-MSC is at the forefront of supporting DOE and other U.S. Government agencies faced with protecting the nation from increased critical infrastructure threats from both domestic and international actors. ICS-MSC unifies top talent in the INL complex using multidisciplinary teams for technical threat and threat actor analysis, vulnerability assessment, interdependency and impact analysis, solution development, prototypes/demonstrations, and technical training.

INL's critical infrastructure protection and cyber security capabilities and related applications are internationally recognized in areas of energy, national security, and industrial process security, optimization, and control. INL offers unique and extensive capabilities in critical infrastructure cyber and cyber security that can be broadly grouped into three main R&D areas: information and decision-making systems, cognitive science and human-computer/machine interaction, and cyber security.

Natural Gas

Increased production of natural gas (NG) using advance modern horizontal drilling and geological fracturing techniques has spurred not only the replacement of coal-fired power plants with NG combined-cycle plants, but new opportunities for compressed and liquefied natural gas (CNG and LNG) and NG conversion to synthetic liquid fuels and chemicals. INL has extensive experience in NG research highlighted by: a) INL's core capabilities in energy systems analysis, chemical systems engineering and process modeling, b) CNG/LNG production and fuel delivery inventions, c) INL's expertise in unconventional gas and oil production modeling, d) waste water monitoring and treatment assessments, and e) INL's advance vehicle performance testing capabilities which can help DOE and commercial industry overcome technology and market barriers to expanding NG use in the transportation energy sector. These barriers include defining Department of Transportation (DOT) standards for CNG/LNG composition and physical properties, LNG filling station design and operation requirements, and specifications and manufacturing techniques for enabling equipment such as stationary and vehicle fuel tanks.

INL is currently proposing a comprehensive NG technical, economical, and environmental analysis to the DOE Clean Cities that would identify logistical sensitivities across the whole U.S. NG value chain from production to end use markets. This type of analysis is critical to building an optimal NG fuels infrastructure. INL may also contribute to the analysis of NG use in hybrid energy systems to help stabilize the electrical grid in coordination with fuels or chemicals manufacturing using excess thermal energy that is available when renewable energy is added to the electrical grid.

A test program that is tantamount to the electric vehicles program is also possible. Foremost, the introduction of NG as a transportation fuel for trucking, railroad, and maritime shipping requires a coordinated development of standards and requirements to establish the nascent LNG and NG fuels market simultaneously with a qualified vehicle fleet. Such standards can be developed from independent testing of NG fuels delivery and vehicles performance efficiency and emissions.

INL is engaging with the Environmental Protection Agency (EPA) to model and measure transport phenomena and water potential ground water contamination associated with tight shale fracturing fluids. Opportunities to monitor and treat co-produced waters may also be explored by applying INL capabilities at the EPA-funded waste water treatment test bed at INL.

Finally, DOD has expressed renewed interest in siting a Liquefied Natural Gas production and filling station on one or more U.S. military bases. This opportunity is being pursued with possible support from the DOE Clean Cities program, and one or more U.S. equipment manufacturing companies. The intent of this project would be demonstration and testing of LNG fuels and transportation efficiency, reliability, environmental benefits, and energy security.

Water Security Test Bed – EPA

The potential for contaminating water supplies is a threat to citizens of the U.S.; EPA was directed by the Homeland Security Presidential Directive 21 to address this threat. The EPA selected INL to create a Water Security Test Bed (WSTB) "because the laboratory has scientists capable of pursuing EPA's and DOE's mutual interests in treating municipal scale pipe and water contaminated with radionuclides, chemical, and biological contaminants."

The WSTB utilizes municipal-scale components and has the capability to test a full range of contaminants. This larger capacity is essential for developing and evaluating detection and decontamination options. INL test bed provides sufficient security, and an adequate supply of used water pipes, potable water, and wastewater treatment capabilities to successfully conduct these experiments. This research is intended to mitigate the incidence and magnitude of the threat and consequence of natural and insidious events involving the nation's drinking water infrastructure and water supplies

Wind and Geothermal

As a multi-mission national laboratory, INL has a responsibility to extract the greatest benefit from the capabilities it stewards to address pressing national challenges in energy and national security, and to be an asset for our regional stakeholders. INL has a long history in deploying fundamental engineering, geoscience, chemistry and physics capabilities – the foundations of our national nuclear laboratory assets base, to address challenges at the heart of the national clean energy grand challenge, and of keen interest and importance to regional stakeholders.

INL capabilities have proven instrumental in advancing geothermal energy development in Idaho and the West, in providing science-based understanding of geophysical systems that help policy makers and regulators make fact-based decisions, in assisting the DOD in deployment of secure energy systems, and a variety of other critical needs. INL will continue to promote the entrepreneurial and creative spirit to identify needs and deploy our capability to address these and other challenges including unmanned aerial vehicle deployment, advanced manufacturing processes and methods, energy-water and water systems issues, secure and efficient renewable energy systems, sustainable carbon conversion and extraction, to name a few.

National User Facilities

Advanced Test Reactor National Scientific User Facility (ATR NSUF)

DOE designated the ATR and associated post-irradiation examination facilities at MFC and CAES as a National Scientific User Facility (ATR NSUF) in April of 2007. This designation allows broader access to nuclear energy researchers, helping to ensure the long-term viability of nuclear energy through a robust and sustained research and development effort. Researchers from universities, laboratories, and industry collaborating through the ATR NSUF facilitate the prospect of advancements in basic and applied nuclear research and development to help meet the nation's energy security needs.

The ATR NSUF is proud to offer users not only the advanced test reactor and post-irradiation examination capabilities of INL, but also of the eight current laboratory, university, and industrial partners. As the Partnership Program expands, other university and national laboratory capabilities will become available to users, expanding the opportunities for science and technology advances.

Advanced Test Reactor

The ATR is considered to be among the most technologically advanced and versatile nuclear test reactors in the world. The unique capability of the ATR to provide either constant or variable neutron flux during a reactor operating cycle makes irradiations in this reactor very desirable. ATR based irradiation capabilities have been expanding over the past years to offer more testing capabilities to researchers, and other changes have increased operational reliability. With these changes, ATR offers the ability to conduct static capsule irradiations, instrumented lead irradiations and pressurized water loop (PWL) irradiations which can precisely represent the conditions in various types of reactors. Additional capability enhancements include:

- **Hydraulic Shuttle Irradiation System**: Allows for insertion and removal of capsule experiments during reactor operation. Can be used for short-term testing, short half-lived isotope production, neutron activation analysis, etc.
- **Dry Transfer Cubicle**: A well shielded facility providing ATR the capability to remotely size irradiated experiments in a dry and inert environment and prepare the experiment for shipping to a PIE or other facility.
- **PWL 2A Activation**: Loop reactivation provided a pressurized test loop for commercial nuclear power plant testing for both pressurized and boiling water reactors.
- **Test Train Assembly Facility**: Provides a secure and clean environment in the ATR complex for the assembly and testing of experiments prior to insertion in the ATR or ATRC.

INL continues to seek opportunities to expand ATR capabilities and enhance ATR's ability to meet the research and development needs of universities, industry, national laboratories, international research organizations, and other federal agencies. Additional enhancements are expected to include conversion to low-enriched uranium fuel and a standardized instrument test carrier for instrumentation testing.

Materials and Fuels Complex

MFC provides a highly concentrated set of unique nuclear energy research and development capabilities and infrastructure. The location and concentration of these facilities and capabilities together with MFC's close proximity to ATR, arguably the world's largest and most versatile test reactor, is unique in the U.S. and within DOE. The MFC is a national asset available to universities, industry, national laboratories, international research organizations, and other federal agencies. MFC is available to offer its capabilities and related nuclear science and engineering infrastructure to advance DOE-NE research goals.

MFC is home to nuclear and radiological facilities and laboratories organized into groups depending on the primary focus of research within the group. They are listed here along with a few of the capabilities hosted in each:

- **Post-Irradiation Examination Facilities** – This group includes the Hot Fuels Examination Facility (HFEF), which has the nation's largest hot cells devoted to receipt, processing and examination of highly-radioactive fuel and material samples using both destructive and non-destructive examination. The Irradiated Materials Characterization Laboratory (IMCL) will become operational in 2014. IMCL is a laboratory designed to perform advanced PIE studies and will also be operated to inform decisions about future PIE investments.

  As a Hazard Category 2 nuclear facility, it was designed and constructed to be flexible and reconfigurable in order to support a broad range of research in irradiated and nonirradiated materials.

IMCL will initially operate using existing PIE equipment which will significantly improve equipment access and sample analysis throughput. In addition, efforts are underway to install new state of the art PIE equipment at IMCL such that it can be operated in a remote environment, enabling analysis on more highly irradiated fuels and material samples. The multi-year effort to install these capabilities along with needed shielding and confinement is in progress.

Capabilities include:

- Neutron radiography
- Precision gamma scanning
- Eddy Current examination capability planned for FY15
- Fission gas sampling
- Fuel accident condition simulation testing
- Full metallographic and ceramographic characterization

- **Research Laboratories** – This group includes several labs and fabrication facilities with numerous hot cells and gloveboxes dedicated to examination and radiochemical analysis of pre- and post-irradiation samples, as well as facilities focused on fabrication of fuel and materials for irradiation and other testing. Capabilities include:

  - Full suite of fuels and materials radiochemistry analytical capabilities
  - Electron microscope analysis including Scanning Electron Microscope, Transmission Electron Microscope, Focused Ion Beam and Electron Probe Micro-Analyzer
  - Thermophysical properties measurement of uranium- and transuranic-containing fuels and materials
  - Thermal ionization, multicollector inductively-couple plasma mass spectrometry
  - Plate fuel fabrication with high-enriched fuel
  - Metallic and ceramic high-enriched rod fuel fabrication
  - Production of radiological standard and reference materials.

- **Spent Fuel Treatment Facilities** – This group includes INL's FCF and several other fuel storage and handling facilities, all focused on used fuel disposition, separations, and nuclear materials management research. Most notably this includes:

  - Engineering-scale pyroprocessing equipment in FCF for irradiated fuels: driver and blanket element choppers, Mk-IV and Mk-V electrorefiners, liquid cadmium cathode, cathode processor, and casting furnace. Metal waste form furnace in HFEF

- Laboratory-scale pyroprocessing equipment in HFEF for irradiated fuels: molten salt furnace for electrochemical oxide reduction and electrorefining, high temperature furnace for off-gas capture and distillation

- Radiochemistry Laboratory (RCL). Aqueous separations research facility with analytical instrumentation, fumehoods, and gloveboxes

- Argon-atmosphere gloveboxes with molten salt furnaces for electrochemical studies. Engineering-scale ceramic waste form furnace for qualification studies. ICP-MS and Thermal Gravimetric Analyzer/ Differential Scanning Calorimeter/ Differential Thermal Analyzer instrumentation.

- **Secure Facilities** – This group includes facilities focused on assembly and testing of radioisotope power sources for deep space exploration and other missions and also includes storage and experiment space for national security-related research and training. This includes:
  - Transuranic-containing fuel fabrication on the lab scale for both metallic and ceramic fuels
  - NHS and DHS wide range of forensic, detection and contaminant dispersion training and experiment facilities at the NRAC and ZPPR facilities
  - Digital Radiography
  - Radioisotope Power Systems assembly and testing.

Biomass Feedstock National User Facility (BFNUF)

BFNUF is one of the premier facilities in the U.S. for scientific and technical investigation of biomass feedstock evaluations and preparation, including scientific, technical, and engineering investigation for transforming biomass feedstocks into consistent, quality-controlled commodity products that can be efficiently handled, stored, and transported to biorefineries in support of biomass based energy security applications. EERE sponsors the BFNUF and INL offers its services to the bioenergy industry, academia, other government agencies and EERE biomass technology programs. The BFNUF advances U.S. energy security by meeting the needs of researchers for an easily accessible, state-of-the-art, and affordable capability. In addition to DOE, several other government agencies, including the U.S. Departments of Agriculture and Defense also have keen interests in developing biomass energy resources.

The User Facility:

- Supports academic, industrial, and federal researchers working at the forefront of scientific and technical understanding
- Supplies a full range of equipment, facilities, personnel, and services needed to advance the science and technology of biomass feedstock evaluations
- Provides accessible, affordable, reliable and leading-edge capabilities to the scientific and industrial community.

Key mission of the BFNUF is to develop major innovations in biomass based energy applications, improve regulatory understanding of new biomass technologies and refine industrial performance of feedstock supply systems, including for hybrid energy systems.

The BFNUF will contribute to major developments in energy applications with high value for the nation, including:

- Developing the scientific, technical, and engineering understanding of biomass feedstock materials for the advancement of U.S. energy security
- Improving regulatory understanding of new technologies
- Improving the industrial performance of current and future energy supply systems including hybrid energy systems.

The BFNUF is located in the new ESL. The ESL provides work space and tools to principal investigators that conduct research and development to reduce technical and economic risks associated with the deployment of new energy technologies. This support infrastructure facilitates moving new energy security concepts from the realm of scientific and engineering investigation to the marketplace of commercially scalable and economically driven industrial processes and new consumer products. Three related energy system programs currently use the majority of the space, including Biofuels and Renewable Energy, Energy Storage and Transportation and Hybrid Energy Systems Testing.

Wireless National User Facility (WNUF)

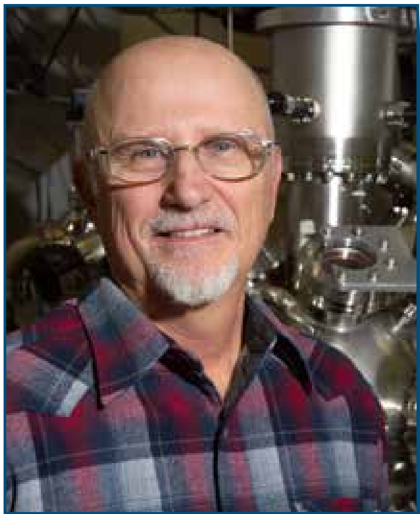
In establishing the Wireless Test Bed as a National User Facility in January 2013, the DOE asserted U.S. leadership in full-scale RDD&D and scientific investigation of wireless communications systems. "The energy security of our nation requires sustainable innovation, development and deployment of secure and resilient communications technologies that are scientifically proven and demonstrated to operate at scale," U.S. Deputy Secretary of Energy Daniel Poneman said. "With this new Wireless National User Facility, DOE will provide the nation with unmatched research and demonstration capabilities."

While the wireless test bed's capabilities have been well utilized by government users for over a decade, use of the national resource is now extended to commercial and academic users. INL's isolated location paired with DOE's significant investment in infrastructure provides the ideal environment for full-scale wireless research. WNUF's unique capabilities have already enabled researchers to address national challenges in infrastructure security, communications interoperability, spectrum utilizations, and the reliability of wireless technologies. Examples include:

- Assistance with analysis of radio frequency (RF) coverage and network configuration recommendations
- Custom simulations of specific radio frequency configurations, and network design recommendations
- Contributions to the critical communications aspect of the DOE Smart Gird initiative
- Prototyping of out-of-band networking for multimedia communication during emergencies that seamlessly integrates several communications methods
- Formulating technology visions and strategies for a new government-wide architecture
- Hosting of wireless spectrum researchers from all facets to allow focus on accelerating the integration and experimentation of prototype research under the broad area of spectrum-using technologies and applications.

It is critical that the research on spectrum using concepts and architectures that has been done and proven in indoor environments is well understood, collaborated upon and transformed into deployable technologies by industry and government. This can be achieved through the WNUF which supports open collaboration between the research communities along with integrated outdoor test facilities for performing realistic research experimentation across various bands and applications.

Mentoring Ladder



Dr. Jim Delmore.

INL's story would not be complete without the enthusiasm and passion our researchers have for their work and in preparing the next generation of science professionals. This Mentoring Ladder has become an innovative way INL's senior scientists transfer their enthusiasm, discipline and ethics associated with science and research from one generation or group to another.

I invited Gary Groenewold to join the team in ~1989 because we had two new programs funded, I needed him to help get these programs off the ground, and shortly after that to take over the programmatic direction. By offering mentoring I was able to get Gary off to a good start. Helping Gary be successful in turn helped the rest of the team be successful. With the entire team being more successful I also became more successful. A team is either successful together or they fail together. So what is there about mentoring that is not to like?

– Dr. Jim Delmore, Senior Scientist and INL Fellow

I had the opportunity to work with junior staff during the conduct of multiple projects over the past two and a half decades. They turned out to be a group of really bright people, and it dawned on me that if I could help them to improve their ability to think, everybody would benefit. Frequently, they would challenge my view of the universe, which I must admit was annoying at times. But I decided that I needed to encourage that mindset – it compelled transparency and clarity on my part with regard to motivation, approach and interpretation, and in many instances resulted in modifying our thinking. I think this set an example for how things should be done. In addition, I made sure that my collaborators were properly credited for what was accomplished, particularly on the author line. What happened was that they became invested in what we were doing, and began contributing to the research at a high intellectual level.

- Dr. Gary Groenewold, Senior Scientist, Chemist

I am fortunate to have mentored numerous interns, subcontract personnel and junior staff. Several of these individuals such as Rachel Emerson and Amber Hoover, are now full time staff and continue the legacy by assisting in mentoring of new interns and as primary mentors for junior technical staff and assigned visiting faculty. The real legacy of Jim Delmore, through Gary Groenewold is the success of these new scientists whose lineage goes all the way back to Jim's early mass spectrometry work.

– Dr. Garold Gresham, Interfacial Chemistry

My mentor, colleague, and friend, Gary Groenewold, trained me to the INL standards and expectations that I needed to know to be a successful INL researcher. Gary encouraged me to publish in peer-reviewed journals, provided opportunities to present results at conferences, and taught the value of networking. Gary's open door policy facilitated regular review and evaluation of data in order to optimize experimental parameters and establish a path forward. Gary created a legacy that I continue to share with other early career researchers.

- Anita Gianotto, Research Management System Lead

"TELL ME AND I FORGET, TEACH ME AND I MAY REMEMBER, INVOLVE ME AND I LEARN" BENJAMIN FRANKLIN

L to R: Rachel Emerson, Amber Hoover, Dr. Garold Gresham, Dr. Gary Groenewold, Anita Gianotto and Dr. James King.

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